Diamonds found in Johannesburg more than 80 years ago reveal how the ancient Earth was shaped

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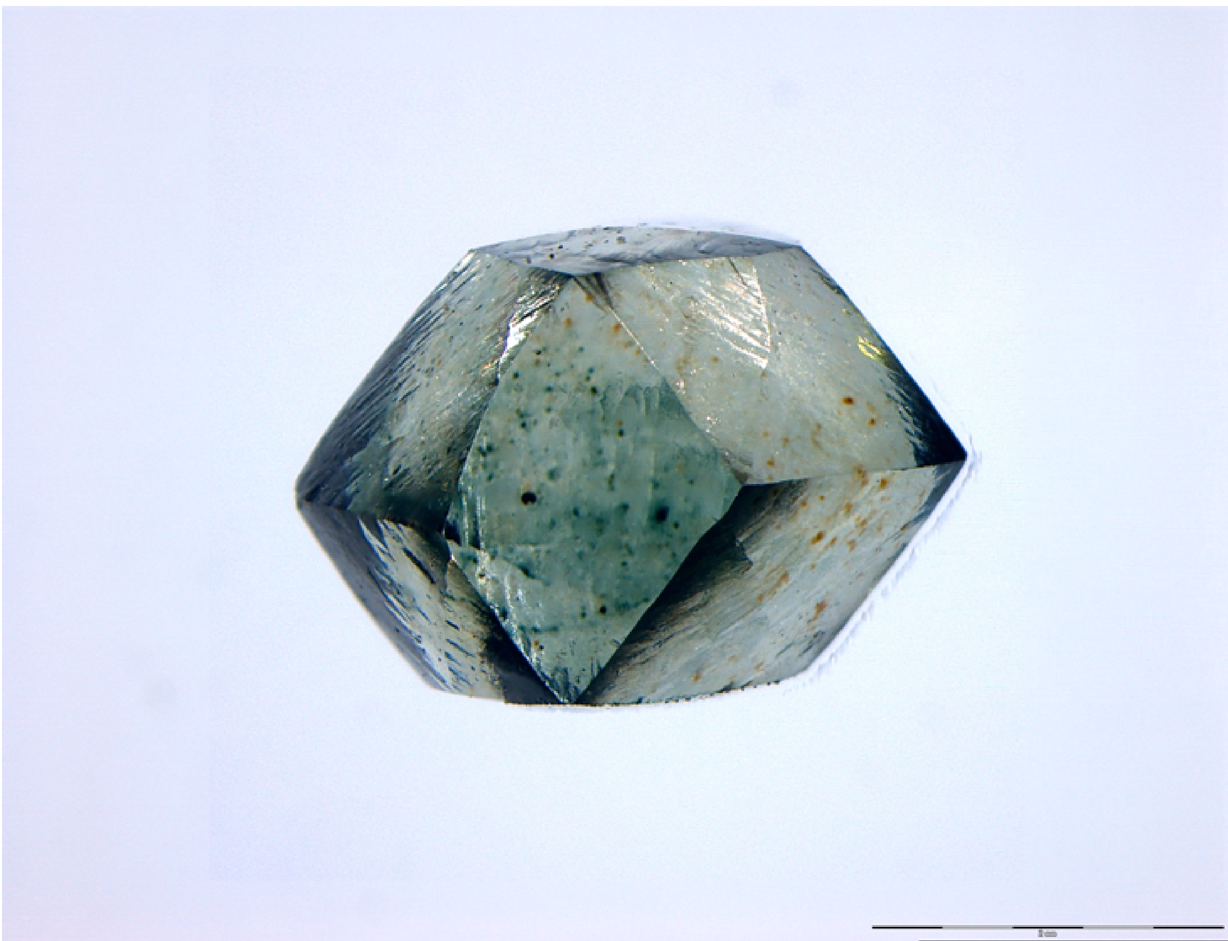
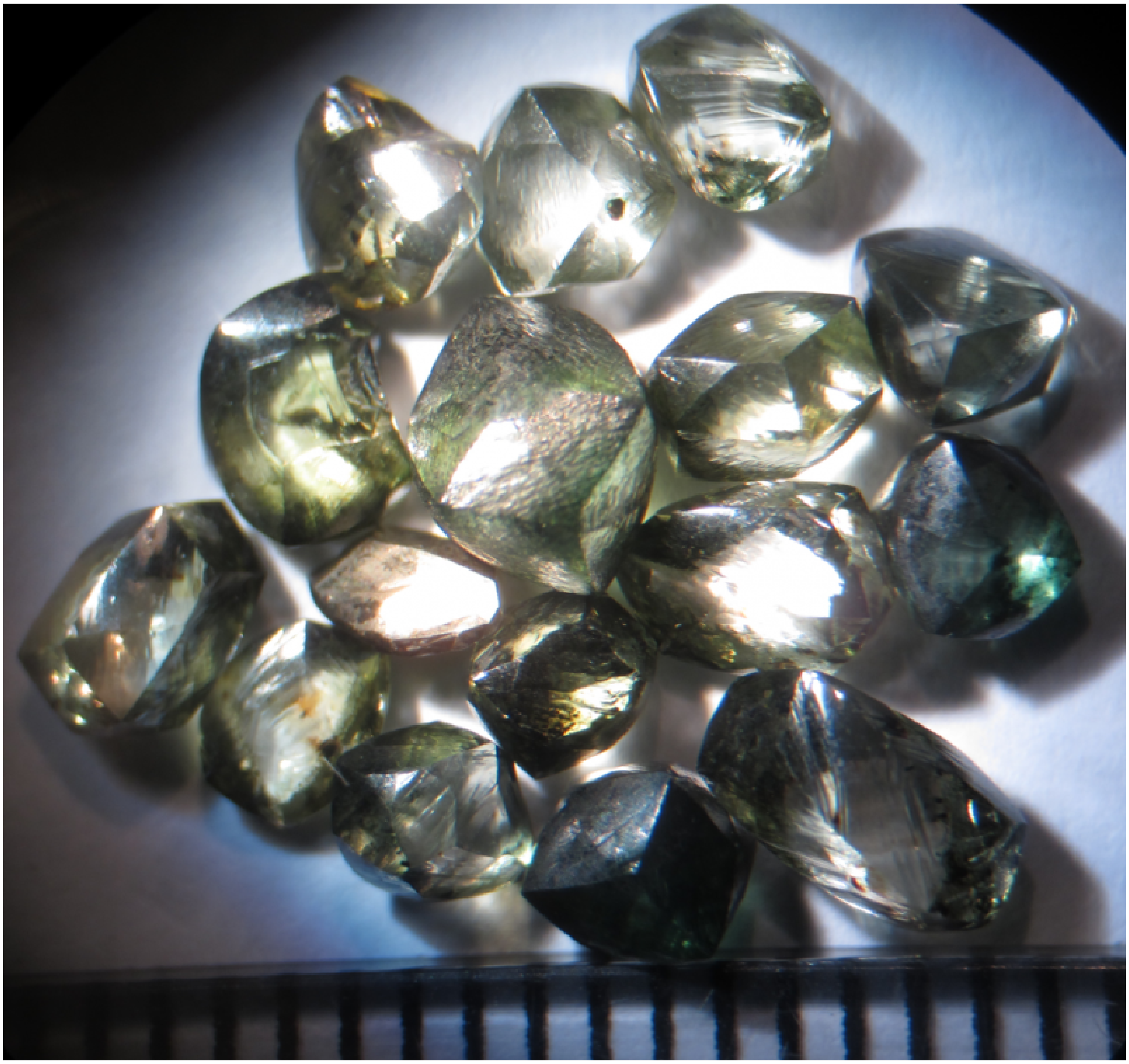


A specimen of a Witwatersrand diamond. Credit: Wits University

Diamonds dug up from ancient rock formations in the Johannesburg area, between 1890 and 1930 - before the industrialisation of gold mining - have revealed secrets of how the Earth worked more than 3.5 billion years ago.

The three diamonds, which were extracted from the 3 billion-year-old Witwatersrand Supergroup - the rock formation that is host to the famous Johannesburg gold mines - were investigated by Dr. Katie Smart, Prof. Susan Webb and Prof. Lewis Ashwal from Wits University, Prof Sebastian Tappe from the University of Johannesburg, and Dr. Richard Stern from the University of Alberta (Edmonton, Canada), to study when modern-style plate tectonics began to operate on planet Earth. The diamonds were generously provided by Museum Africa, located in Johannesburg, with the assistance of curator Katherine James.

"Because diamonds are some of the the hardest, most robust material on Earth, they are perfect little time capsules and have the capacity to tell us what processes were occurring extremely early in Earth's history," says Dr Katie Smart, a Lecturer at the Wits School of Geoscience and the lead researcher on the paper, Early Archaean tectonics and mantle redox recorded in Witwatersrand diamonds, that was published in the journal, *Nature Geoscience*, in January.



A cluster of the Witwatersrand diamonds. Credit: Wits University

The Earth is approximately 4.5 billion years old, and while a rock record exists from about 4 billion years ago, the complex preservational history of the most ancient rocks exposed on Earth's surface has led to a heated debate amongst Geoscientists on when plate tectonics began operating on Earth. Many researchers believe plate tectonics began in the Archaean (the Eon that took place from 4 to 2.5 billion years ago), although the exact timing is highly contested.

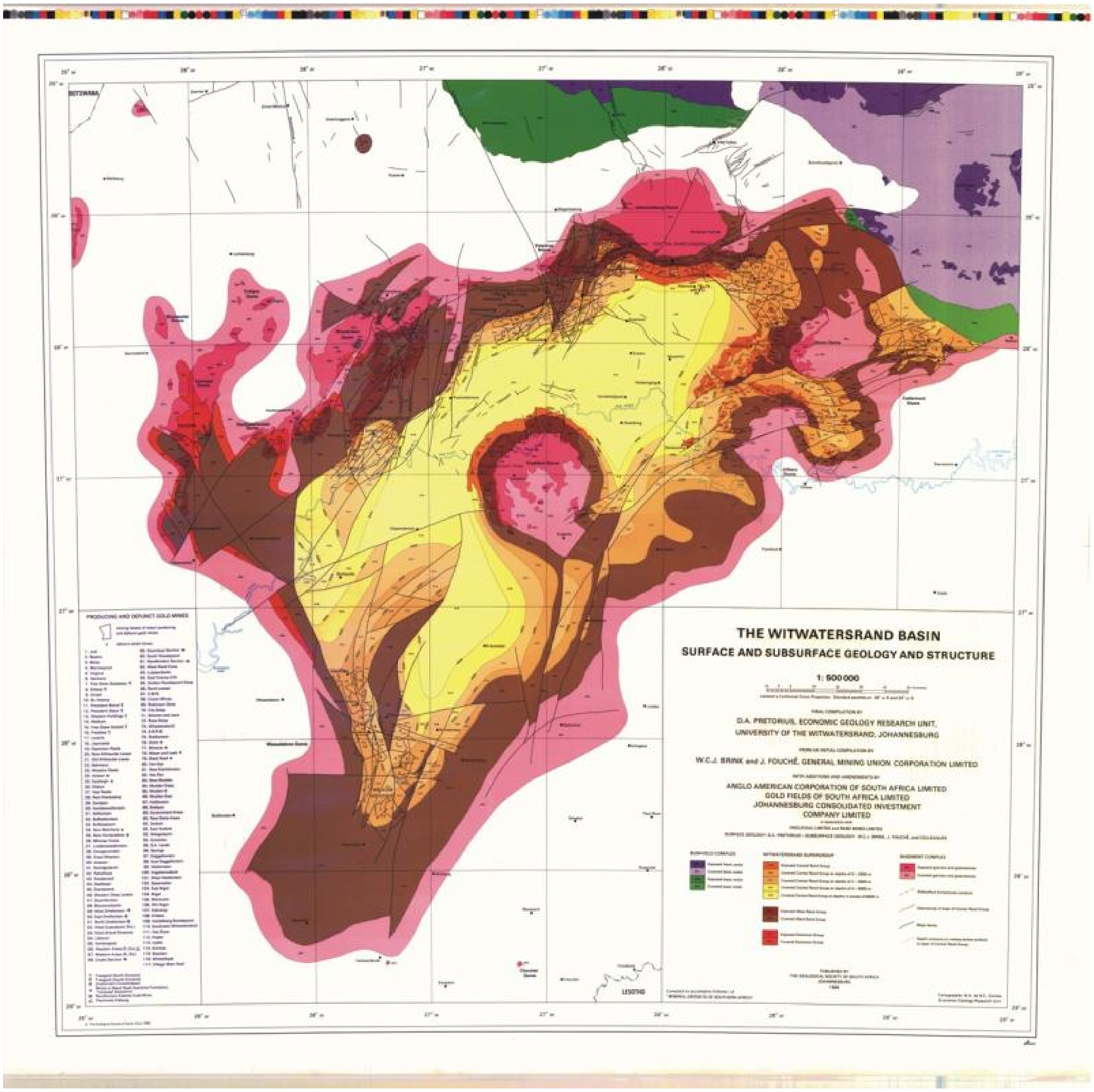
While the diamonds of this study were found in 3 billion-year-old sedimentary rocks, diamond formation occurred much deeper, within Earth's mantle. Additionally, based on the nitrogen characteristics of the diamonds, they also formed much earlier, around 3.5 billion years ago. Transport of the diamonds to the surface of the Earth by kimberlite-like volcanism, followed by their voyage across the ancient Earth surface and into the Witwatersrand basin, occurred between 3.5 and 3 billion years ago.

By using an ion probe to analyse the carbon and nitrogen isotope compositions of the Witwatersrand diamonds, which have been pristinely preserved for more than three billion years, Smart and her team found that plate tectonics was likely in operation on Earth as early as 3.5 billion years ago.

"We can use the carbon and nitrogen isotope compositions of the diamonds to tell us where the source material involved in the formation of the Witwatersrand diamonds over 3 billion years ago came from," says Smart.

"The nitrogen isotope composition of the Witwatersrand diamonds indicated a sedimentary source (nitrogen derived from the Earth's surface) and this tells us that the nitrogen incorporated in the Witwatersrand diamonds did not come from the Earth's mantle, but that it was rather transported from Earth's surface into the upper mantle through plate tectonics. This is important because the nitrogen trapped in the Witwatersrand diamonds indicates that plate tectonics, as we recognise it today, was operating on ancient Archaean Earth, and actively transported material at Earth's surface deep into the mantle."

Earth as a planet is unique because of the dynamic process of plate tectonics that constantly transports surface material into the Earth's mantle, which extends between 7 km to over 2800km below Earth's surface. The process is driven by both convection cells within the Earth's mantle and the character of crustal plates at Earth's surface, where newly formed oceanic crustal plates are formed at spreading centres at mid-ocean ridges and then pushed apart. Older, cooler and more dense crust at convergent plate margins is then pulled into, or sinks, into the mantle at subduction zones. The subduction of crustal plates into the mantle can also carry sediments and organic material deep into the Earth's interior.



A map of the Witwatersrand Basin. Credit: Economic Geology Research Institute (EGRI)

The plate tectonic process is vital for shaping the Earth as we know it, as the activity of plate tectonics causes earthquakes, volcanic eruptions, and is responsible for constructing Earth's landscapes, such as deep sea trenches and building of mountains on the continents.

"Various researchers have tried to establish when exactly plate tectonics started on Earth, but while there are many investigations of ancient rocks on Earth's surface - like the 3.5 billion year old Barberton Greenstone Belt here in South Africa, or the 4 billion year old Acasta Gneiss in northwest Canada - we are looking at the problem from a different viewpoint - by investigating minerals derived from Earth's mantle," says Smart.

"We are not the first research group to study diamonds in order to tell when plate tectonics began, but our study of confirmed Archaean diamonds has suggested that plate tectonics was in operation by at least 3.5 billion years."

About the research:

- Researchers acquired three Witwatersrand diamonds from Museum Africa. These diamonds were cut by laser and saws to create thin diamond plates.
- Diamonds sometimes contain "inclusions" of minerals, which can be used to date the diamonds using radiogenic isotopes. Diamonds themselves cannot be directly dated, and it is assumed that the diamond and diamond inclusion formed together at the same time. The oldest diamond inclusion known has been dated to be 3.5 billion years old.
- The age of the Wits diamonds is confirmed due to their derivation from the 3 billion-year-old Witwatersrand sediments, and are likely 3.5 billion years old based on the nitrogen characteristics of the diamonds.
- The goal of the study was to complete carbon and nitrogen isotope analyses of the diamond plates using an Ion Microprobe.
- The specimens were analyzed by Dr. Richard Stern and Dr. Katie

Smart at the Canadian Centre for Isotopic Microanalysis at the University of Alberta, Edmonton, Alberta using a state of the art Cameca IMS1280 ion microprobe. An ion microprobe analyses geologic specimens using SIMS (Secondary Ion Mass Spectrometry) at a very fine spatial resolution, and in the case of this study, achieved spatial resolution of

- The final product is a stable isotope ratio: in this case carbon (13C/12C) and nitrogen (15N/14N) isotope compositions plus nitrogen contents of the Witwatersrand diamonds were determined. Due to the sensitivity and spatial resolution required for the study, there are only a few labs worldwide that can complete these complex analyses.
- The results showed that the source of the nitrogen involved in the formation of the Witwatersrand diamonds was likely sedimentary and derived ultimately from Earth's surface. Importantly, this indicates that the nitrogen must have been transported into Earth's mantle through plate tectonics much earlier than 3.5 billion years ago.

About the Witwatersrand Diamonds

The green Witwatersrand diamonds were found in the Witwatersrand conglomerate, where the gold was found that led to the establishment of the city of Johannesburg.

A number of these diamonds were found between 1890 and 1930, when men were still mining by hand and pick axes. After the industrialisation of the mines in the 1930s, most of the diamonds in the conglomerate were crushed to dust. For this reason, the Witwatersrand diamonds are extremely rare.

The Witwatersrand conglomerate is known to be at least three billion years old. The diamonds that are found in the conglomerate are known as "placer" diamonds. These diamonds did not originate in the conglomerate, but were transported from their original kimberlite sources by secondary means, such as rivers.

Most diamonds are believed to be younger than three billion years old, but as the Witwatersrand conglomerate is known to be three billion years old, the diamonds found in the conglomerate must have been formed more than 3 billion years ago. Thus, they can be referred to as "confirmed ancient diamonds".

More information: Katie A. Smart et al. Early Archaean tectonics and mantle redox recorded in Witwatersrand diamonds, *Nature Geoscience* (2016). DOI: 10.1038/ngeo2628

Provided by Wits University